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SRI Technical Report No. 12

**DETONATION, SHOCK, AND CHEMICAL REACTION PROCESSES IN
EXPLOSIVE DISSEMINATION: BOUNDARY STABILITY AND CAVITATION**

Special Report

by

L. B. SEELY
J. G. BERKE

June 1967



DEPARTMENT OF THE ARMY
EDGEWOOD ARSENAL
Research Laboratories
Physical Research Laboratory
Edgewood Arsenal, Maryland 21010
Contract DA-18-035-AMC-122(A)

STANFORD RESEARCH INSTITUTE
Menlo Park, California

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**Contract DA-18-035-AMC-122(A)
Task 1B522301A08101
SRI Project PAU-4900**

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FOREWORD

The work described in this report was authorized under Task 1B522301A08101, Dissemination Investigations of Liquid and Solid Agents (U). The work was started in January 1965 and completed in May 1967.

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DIGEST

The purpose of this study of boundary instability was to conduct a brief experimental investigation of the explosive-product/liquid interface and the liquid-air interface to ascertain if simple theoretical predictions are realized. The study was carried out with a Beckman Whitley Model 189 framing camera.

Framing camera pictures of the explosive-products/liquid interface under the influence of motion imparted by an explosive show:

1. Some mixing occurs when the shock from the detonation enters the liquid. This early jetting apparently results from irregularities of the explosive surface.
2. If the jetting referred to above is pronounced, it is not prevented by thin metal walls between the explosive and the liquid.
3. For the geometry studied the product-liquid interface is quite stable in the period between entry of the shock into the liquid at the explosive-liquid boundary and its exit at the liquid-air boundary. (There is no acceleration during this period.)

Framing pictures taken after the shock reaches the liquid-air interface show:

1. Rapid acceleration of the products takes place when the first rarefaction reaches the product-liquid interface. (This is a period when instabilities might develop.)
2. The rarefaction wave reflected from the liquid-air surface causes fine random cavitation. There is no experimental evidence of layered cavitation.

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I INTRODUCTION

Among the possible mechanisms by which chemical agents may be lost during explosive dissemination is thermal degradation due to contact with the hot detonation products. True, there are a number of factors tending to minimize the importance of any such effect. For instance, the detonation product gases, particularly those close to the liquid, can be expected to cool rapidly because of both expansion and the work they do on the fill; thus, degradation caused by the hot gases must occur early in the dissemination process if it is to occur at all. Similarly, if this type of degradation is to be serious, a small amount of cold fill must be exposed to a large amount of hot gas. This provides an a priori reason that direct heating of the fill by thermal conduction from the product gases will necessarily involve only a small amount of fill.

On the other hand, such plausibility arguments for ignoring fill-product mixing depend implicitly upon the assumption that the expansion is a well-ordered process without jetting or stagnation, that the fill is a stable chemical compound, and that a degradation reaction, once triggered, will not be able to perpetuate itself. Finally, it is assumed that early product-fill mixing will not affect subsequent degradation mechanisms. In fact it is not clear that such complicated interactions do not play an important role in specific practical munitions with particular agents (or may be expected to play such a role with future agents).

A small experimental program was undertaken to observe detonation-product/liquid surfaces undergoing the processes to be expected in the early stages of dissemination. A number of useful conclusions can be drawn from even so small an effort. These conclusions are not necessarily unexpected but certainly worth experimental confirmation. In addition, an observation of the liquid-air interface pointed up the importance of random cavitation in the first rarefaction wave. Again, the result is hardly unexpected in view of the extensive study of underwater

explosions. However, the existence of bulk cavitation needs to be recognized as an early phase in dissemination. It probably overshadows the highly idealized process of layered spalling and may also have a direct bearing on the agent degradation problem.

II PRODUCTS-LIQUID INTERFACE

A. General

An experimental program to study instabilities of the interface between the explosive products and the fill is immediately beset with difficulties of observation. In the case of the flash X-ray technique the resolution required during early motion of the boundary is the limiting factor. With optical techniques the difficulties are exclusion of shock light, illumination of the surface, and collection of reflected light in such a manner that it is not seriously distorted by the oncoming shock. The optical problems are particularly serious in three-dimensional geometries--even in the symmetric spherical case. It was therefore decided to study a quasi one-dimensional case in which a P-40 plane-wave lens (with or without an additional 1/2-in. pad of Comp. B, depending on the case) was fired under water. The plane shock emerging from the lens into the water is easier to see through than the curved shock of the spherical case. The edges of the shock, although curved as the main shock advances into the liquid, are much weaker than the flat part of the wave and might be expected to permit observation of the interface through them at all but the earliest times.

Question naturally arises concerning the utility of measurements on an admittedly artificial system; it is clear that a plane shock is unlikely to be used in a munition. The next most complicated case, the spherically symmetric one, is not much more realistic. Actual munitions involve very complicated geometries indeed and, for the early times we are concerned with, produce shocks that are not uniformly divergent. For instance, the E-13OR3 bomblet has a spherical exterior case and thus could be designed to produce a relatively unperturbed symmetric spherical flow. In fact, it contains a cylindrical burster initiated at one end; the fill chamber is interrupted at both ends of the burster by fuze bodies. The expansion is by no means simply cylindrical during the development of the detonation wave and after the wave is reflected at the fuze body,

the flow becomes very complex. Cylindrical flow, even if perfect, would not fit the spherical outside shape of the bomblet. Thus, even with this simplest of experimental munitions, simple spherical divergent flow does not occur. An experiment designed for spherical symmetry will not be noticeably closer to an actual case than the plane wave we have chosen. The plane wave has the great virtue that it is simple for experimental study by optical means. The product-liquid surface can be observed during periods of mixing or stability. Extrapolation of the phenomena observed can probably be made to the spherically symmetric case, although detailed application to a complicated munition may become very involved.

Spherically symmetric explosions have been studied in some detail and involve a number of features that are not involved in the plane wave case (1,2). The most general effect is a rapid falloff in pressure with distance due to the divergent nature of the flow. In addition, an eventually inward-running shock forms at the back of the Taylor wave, and after reflection emerges as a second outward-going shock. These effects also carry over to the expansion of the fill, (3, Fig. 3.2, p. 30) and they can be expected to be particularly strong at low fill-burster ratios.

B. Shock Velocities

Two experiments, designed as preliminary investigations of the product-liquid interface, were useful in establishing the strength of the shock. A box approximately 7 x 7 x 7 in. was constructed of Plexiglas. A P-40 plane-wave lens* with an additional 1/2 in. thick pad of Comp. B-3 was set in a cavity cut in the bottom of the box so that 1/16 in. of Plexiglas remained between the Comp. B and the water. The box was arranged in front of a Beckman Whitley Model 189 Framing Camera and backlighted with an exploding bridgewire to provide silhouettes of the shock.

A selected frame, at 8 μ sec after the shock entered the water, is shown in Fig. 1. A plot of the position of the shock front is shown in Fig. 2. The entering shock velocities from the two charges were

* Obtained from S. L. Mason/Mason Hanger Co., Amarillo Texas. The P-40 consist of a conical Baratol (76% $\text{Ba}(\text{NO}_3)_2$, 24% TNT) center overcast with Comp B (60% RDX, 40% TNT, plus less than 2% additives).

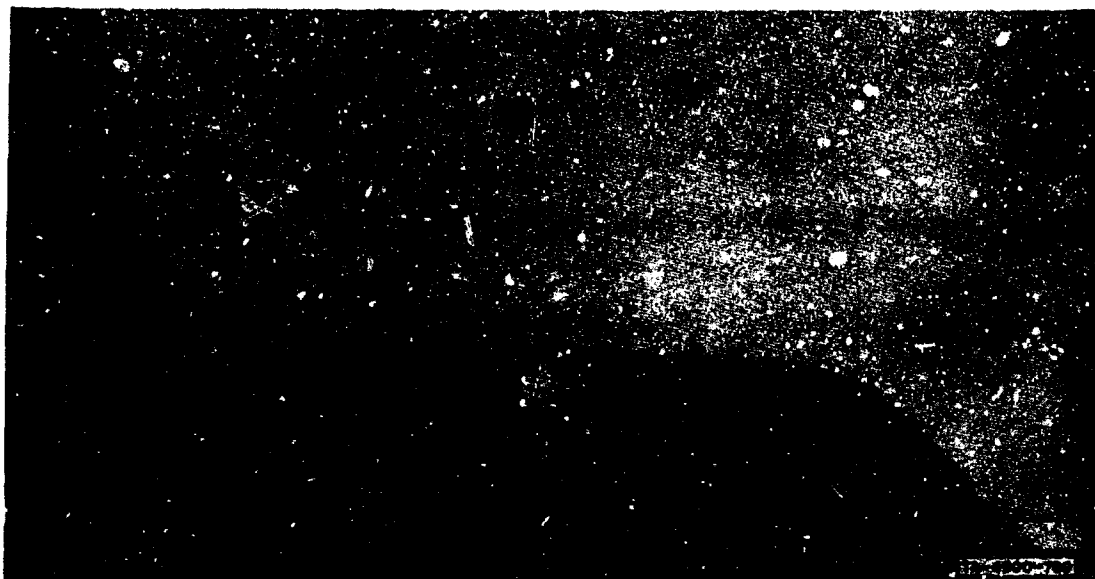


FIG. 1 FRAMING CAMERA PICTURE OF SHOCK ADVANCING IN WATER 8 μsec AFTER ENTRY. The light patterns are caused by refraction of the point-source backlight. The dark, fine structure near the bottom arise from jetting. Its position cannot be determined from this type of photograph, whose purpose was a measurement of the shock velocity. SRI Shot No. 10963.

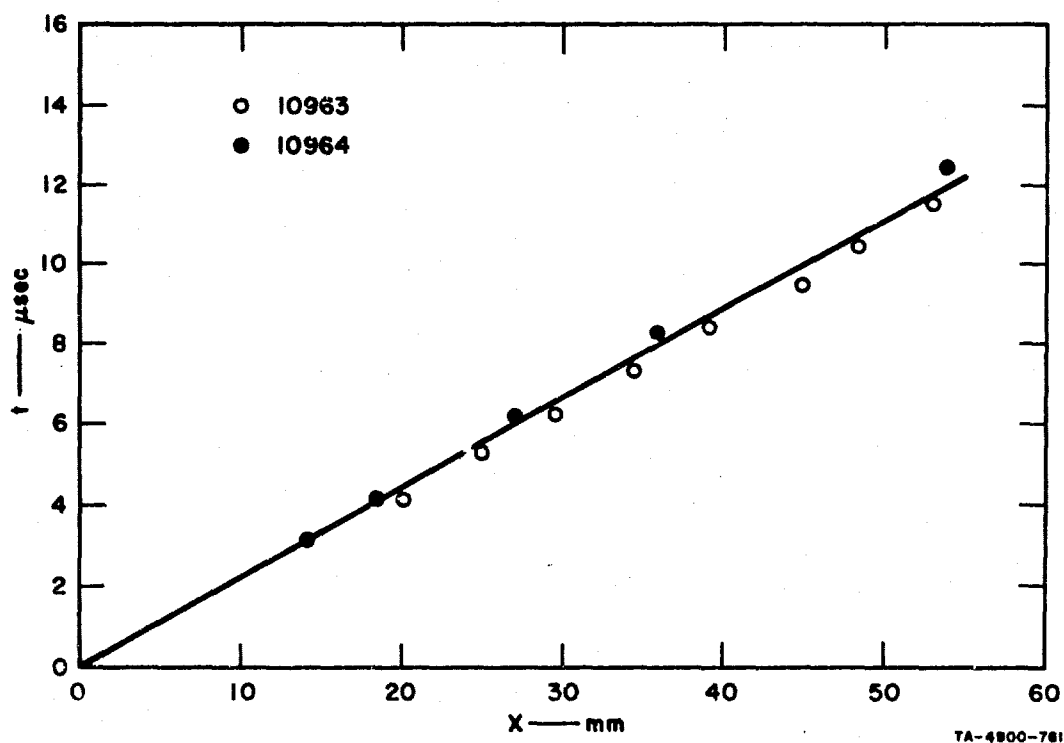


FIG. 2 SHOCK FRONT POSITION (x) PLOTTED AGAINST TIME (t)
SRI Shot Nos. 10963 and 10964.

4.6 mm/ μ sec and 4.2 mm/ μ sec. The apparent particle velocity was about 1.6 mm/ μ sec. Thus, the entering pressure is about 70 kbar, which is in reasonable agreement with published data on the Hugoniot of water (4).

The entering pressures for the shocks in water reported in the following sections correspond roughly to this value when a thin pad of Comp. B-3 was used over a P-40 plane wave lens. When the plane wave lens was used alone, the pressure was somewhat lower, but the pressure-time history of the wave from a P-40 is sufficiently complicated to prevent simple calculation of the pressure in water from the pressure to be expected in Baratol when overdriven (as it would be in a P-40).

C. Observations of Mixing at the Explosive-Liquid Interface

1. Experiments

The successful technique finally used to obtain high quality framing camera pictures of the explosive-liquid interface involved the experimental arrangement shown in Fig. 3. The optic axis of the framing camera made an angle of 22° with the plane being viewed. Lighting was from directly above the plane. In some shots, an angled matte reflector facing the camera improved the definition of the shock front and increased the illumination of the detonation products.

Shot 11433 serves as an example of the products-liquid interface produced by the explosion when the surface of the Comp. B is smooth and in direct contact with the water. The sequence of events is typical of shocks entering liquids under a wide variety of conditions. Four frames are shown in Fig. 4.

When the shock first enters the water it is apparently opaque. Judging from the results of other techniques used in preliminary investigations, the difficulty in photographing the interface at this stage does not result from absorption of light in the shock but instead arises from the sharp change in index of refraction at the shock front. As the shock advances, light begins to penetrate the shock and is reflected back to the camera. Parts of the shock cause considerable distortion,



FIG. 3 EXPERIMENTAL ARRANGEMENT FOR OBTAINING FRAMING CAMERA PICTURES OF THE INTERFACE BETWEEN EXPLOSIVE PRODUCTS AND LIQUIDS. In this case the explosive surface was artificially roughened with circular lathe cuts.

but at the edge through which light comes to the camera the shock is weak enough to permit a fairly undistorted image of the region of interest. An image of the light source is seen by reflection on the shock front. A somewhat smaller image is focused on the products by the shock acting as a lens. In the last frame in Fig. 4, considerable fine-grain detail can be seen in the products-liquid interface, but apparently no large scale mixing.

In shot 11434 (Fig. 5) the same general features can be observed, but in addition a reflection is visible from each side of a 1/16 in. thick Plexiglas sheet that covered the explosive. Thus we see that for smooth explosive the effect of the plastic sheet is small. There is every indication that it acts for a considerable time as a coherent effective barrier between the products and the liquid.

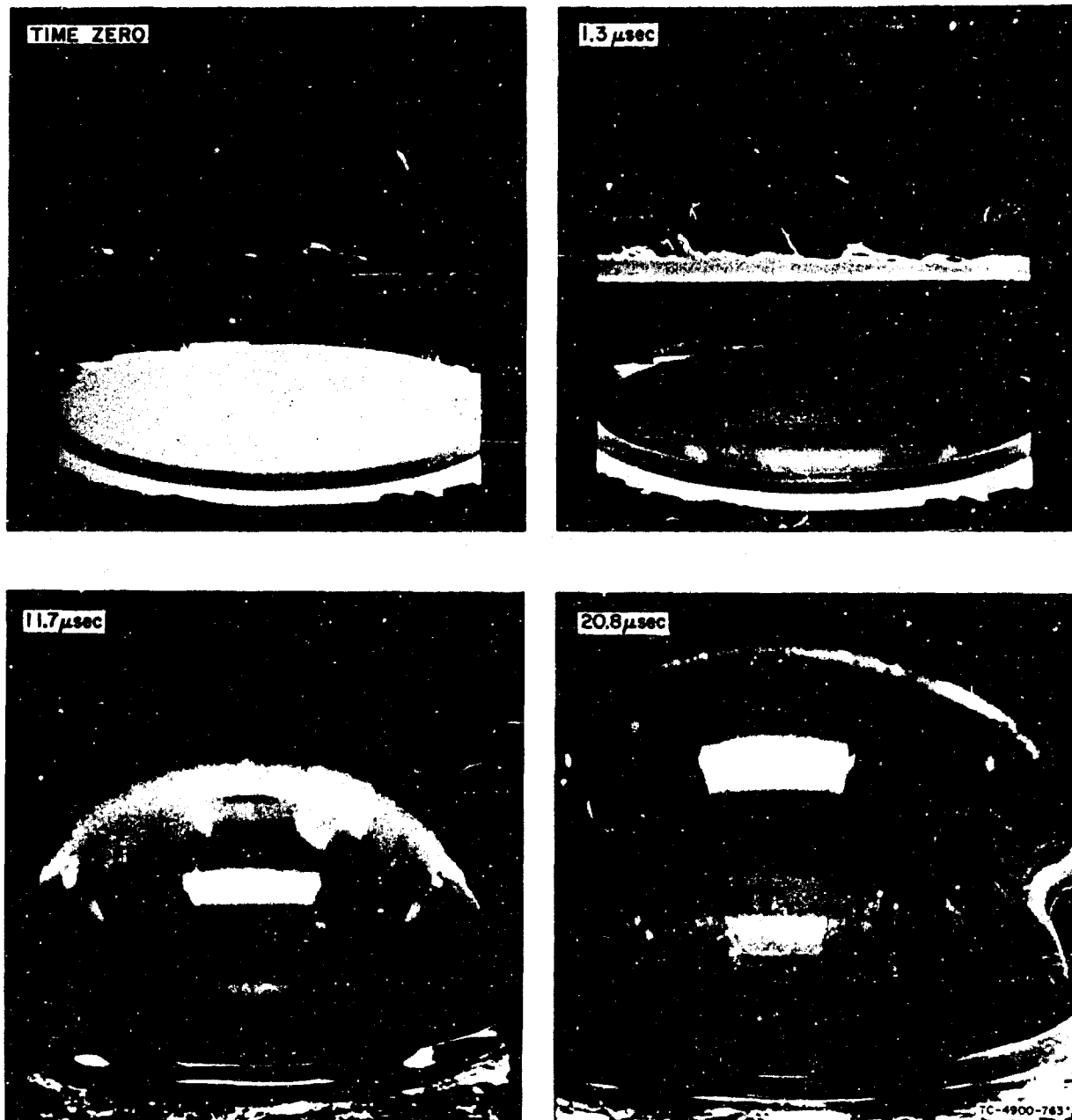
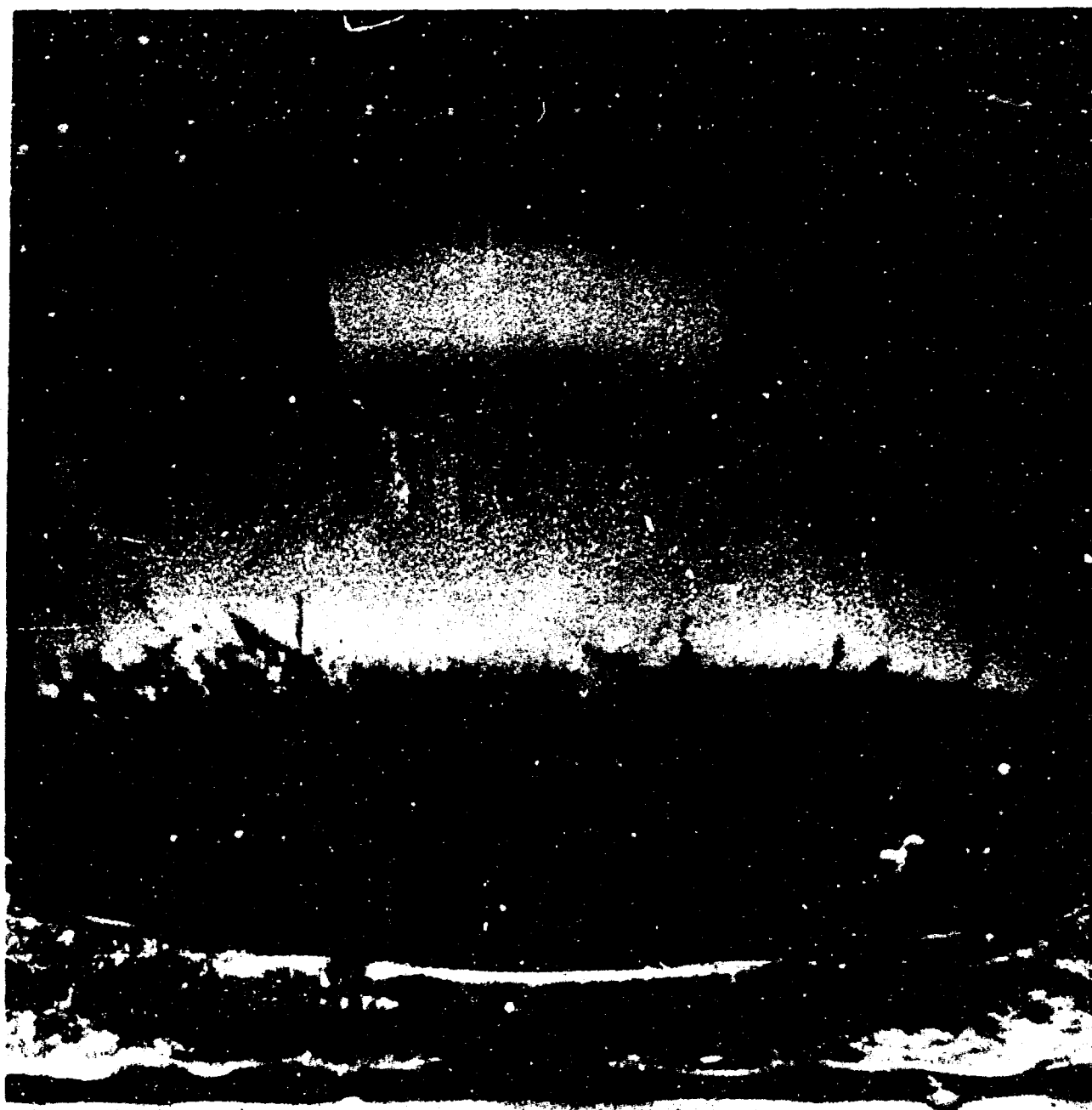


FIG. 4 FOUR FRAMES FROM A HIGH SPEED FRAMING CAMERA SEQUENCE, SHOWING THE INTERFACE BETWEEN EXPLOSIVE PRODUCTS AND WATER. For all such pictures in this report times are relative to the entry of the shock into the liquid. The original explosive surface in this case was smooth. SRI Shot No. 11433. The framing time was approximately 1 μsec .



FIG. 5 SINGLE FRAME OF PRODUCTS-LIQUID INTERFACE WHEN A PLEXIGLAS SHEET WAS INTERPOSED BETWEEN EXPLOSIVE AND WATER. A reflected image of the light source can be seen on the shock front, a refracted image on the products, and a reflection from each side of the Plexiglas. Time $10 \mu\text{sec}$. SRI Shot No. 11434.

A late frame from shot 11246 is shown in Fig. 6. The explosive was in direct contact with the water. The surface was marred by a grainy structure with dimensions of the order of a millimeter. It is apparent from the picture that there was considerable jetting when the shock passed from the explosive into the water. However, we have concluded from study of the whole sequence of pictures that the boundary was stable thereafter because the irregularities do not grow as time progresses. This is undoubtedly due to the fact that the acceleration is close to zero during the period before the rarefaction from the liquid-air interface arrives.



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FIG. 6 SINGLE FRAME OF PRODUCTS-LIQUID INTERFACE FOR AN ORIGINALLY ROUGH, EXPLOSIVE SURFACE. Time 25 μ sec. SRI Shot No. 11246.

A surface irregularity of definable extent was produced by cutting triangular 1/32 in. deep grooves into the Comp. B surface with a lathe. Framing camera pictures showed circular jets corresponding to the position of the grooves. After their formation the size of the jets changed very little, and the late frames show them essentially constant.

A similarly grooved charge was covered with a 1/32 in. brass sheet glued down so that the grooves were not filled with water. A frame at 12.5 μ sec from that experiment (shot 11436) is shown in Fig. 7. The roughness of the products-liquid surface in this case is much greater than when the brass was not present, resulting at least in part from the increased efficiency of jetting action in the air-filled grooves under the brass as compared with the water-filled grooves when the bare charge was used.

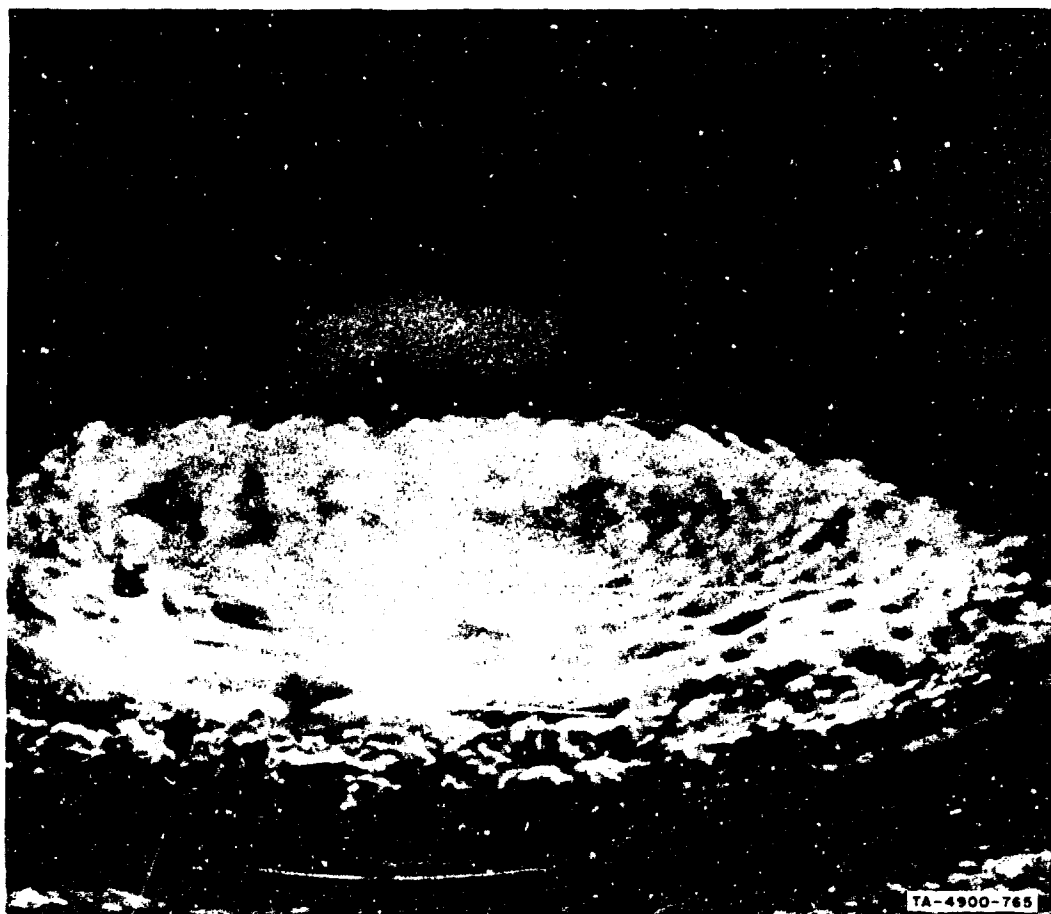


FIG. 7 SINGLE FRAME FROM A SEQUENCE OF FRAMING CAMERA PICTURES SHOWING THE EFFECT OF 1/32 in. CIRCULAR GROOVES IN EXPLOSIVE WHEN A 1/32 in. BRASS SHEET WAS INTERPOSED BETWEEN EXPLOSIVE AND WATER. Time 12.5 μ sec. SRI Shot No. 11436.

2. Conclusions

As a result of these tests we conclude that mixing of the fill with hot detonation products is not likely to be a cause of extensive degradation. It appears that immediately after the shock enters the liquid the boundary is stable. If it later becomes unstable under the action of the rarefaction wave, cooling of the products will already have progressed far enough that degradation will probably be avoided in all but the most unstable agents.* However, jetting under the action of the shock front apparently occurs in proportion to the irregularities of the explosive surface. As a practical result, therefore, the surfaces of bursters should be as smooth as possible. If jetting is pronounced, a metal burster case does not decrease the mixing.

* Cooling is due not so much to expansion (since repulsion energy is high in the original detonation products) but rather to work done in accelerating the fill.

III LIQUID-AIR INTERFACE

Our investigation of the liquid-air interface was undertaken at the suggestion of S. R. Brinkley, Jr.,* who pointed out that bulk cavitation might be expected to occur in explosive expansion of liquids but that it had until that time been neglected as a part of the explosive dissemination process.

Cavitation of liquids under the action of explosives was observed many years ago (5). One of the prominent features observed at the water surface over an explosive charge detonated underwater was the "spray dome," a white mound of water rising under the influence of the shock wave. Dome formation has been studied experimentally chiefly in terms of effects visible from above the surface (6, pp. 392-402). Much of the early theoretical analysis was carried out with the acoustic approximation, although sufficient information on the shock properties of water is now available to permit treatment of dome formation properly, as a shock phenomenon (6, pp. 51-62).

A. Experiments

Cavitation had been observed more or less by accident on the late frames of some of our films taken to show the effect of the rarefaction wave on the explosive-liquid interface. A disturbance at the liquid-air interface was seen after the shock had arrived there. It was extremely bright in reflected light. However, details could not be discerned on these first films because the liquid-air surface was at the very top of the frame and partially obscured by the top of the water container.

The experimental arrangement was changed so that the phenomena at the surface could be observed more advantageously. The container was enlarged from 7 to 24 inches square so that the shock would not strike

* Dr. Brinkley served as a member of the Evaluation Panel on this Project. The suggestion was made during the meeting of the panel at Stanford Research Institute in June, 1965.

the sidewalls during the period of observation. The thickness of water over the explosive plane-wave lens was reduced to 4 inches or less, and the position of the box was adjusted to place the surface of the water on the optic axis. A photograph of this arrangement is shown in Fig. 8. Four frames from shot 11812 are shown in Fig. 9. The framing time was 4 μ sec.

The white cloud seen after the shock breaks through the surface of the water is a region of very finely cavitatted water. The resolution on the original framing camera films is hard to estimate accurately but must



FIG. 8 EXPERIMENTAL ARRANGEMENT FOR VIEWING EFFECTS AT LIQUID-AIR INTERFACE. The oblong boxes at the sides are explosive-argon light sources.

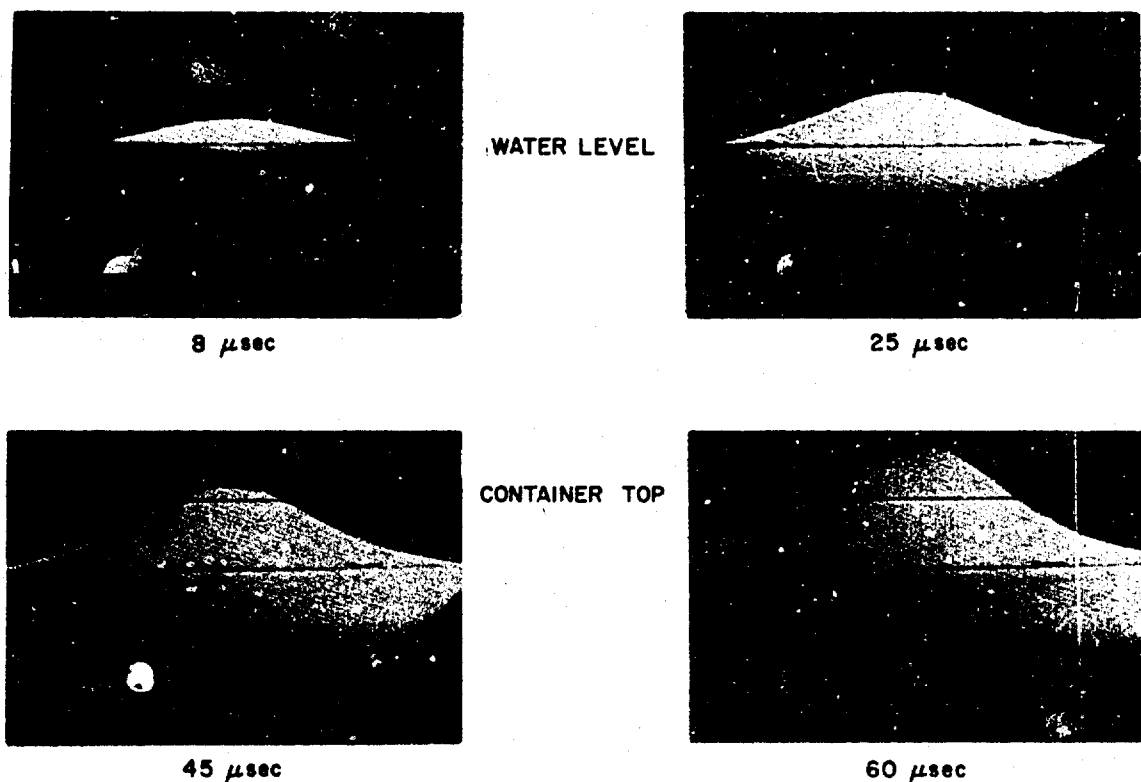


FIG. 9 FINE-SCALE CAVITATION IN A RAREFACTION WAVE IN WATER. Times are measured from breakthrough of the shock at the water surface. SRI Shot No. 11812.

certainly correspond to less than $1/2$ mm in object space; the bubbles are less than this size. Pictures of the white dome were also taken against an argon-flash backlight. Under these conditions the dome was seen to be an efficient light scatterer (i.e., it appeared dark), indicating a bubble size considerably smaller than $1/2$ mm. The cavitated region eventually spreads to the full depth of the box.

An estimate of the shock strength can be obtained from the rate of rise of the center of the dome. The explosive in this case was a bare P-40 plane-wave lens. The original pressure in the shock when it first entered the water was therefore less than the 70 kbar indicated by the shock velocities reported in the foregoing section, since those measurements concerned a P-40 plus a $1/2$ in. thick Comp. B pad. The free surface velocity of the central part of the (cavitated) water was

approximately 1 mm/ μ sec (particle velocity 0.5 mm/ μ sec), corresponding to a pressure as the shock broke through the surface of the water of ~ 15 kbar.

The bright line curving back into the water, seen clearly in the 8 μ sec picture and less distinctly in the 25 μ sec picture, is connected with the density gradient of the rarefaction wave but cannot be assumed to be the head of the wave. The head travels with the speed of sound less the particle velocity of the original wave, and the following gradient becomes less steep as the wave proceeds. Therefore, the position of the line depends on illumination conditions and the stage of development of the rarefaction. The velocity of sound, approximated as the slope of the Hugoniot for water, is about 3.1 mm/ μ sec. The rarefaction is expected to move into the shocked water at sound velocity less the particle velocity in the original wave, or approximately 2.6 mm/ μ sec.

The velocity with which the cavitated region spreads toward the detonation products has been measured at about 1.5 mm/ μ sec in the time interval between 4 and 8 μ sec, falling to 1.1 mm/ μ sec at 25 μ sec. This appears to be below the velocity of sound in the shocked liquid (see above). The velocity of sound in shocked but re-expanded quiescent water is about 1.5 mm/ μ sec (6,7). The position of the cavitation front is plotted in Fig. 10. The cavitation front is in fact trailing the head of the rarefaction wave, and is traveling in a region where the particle velocity opposing the cavitation front has already increased and the temperature of the water has fallen. In spite of these uncertainties the measurements suggest fairly strongly that the cavitation front is subsonic with respect to the water ahead of it. The question should be investigated more thoroughly with experiments designed for that purpose, since it is connected with the value of the tensile strength of water at the stress rates of these experiments. Kennard (8, p. 2) has developed a theory of bulk cavitation in which the "breaking pressure" p_b is assumed to be equal or less than the cavity pressure p_c (the vapor pressure of the decompressed water). If the breaking pressure is less than the

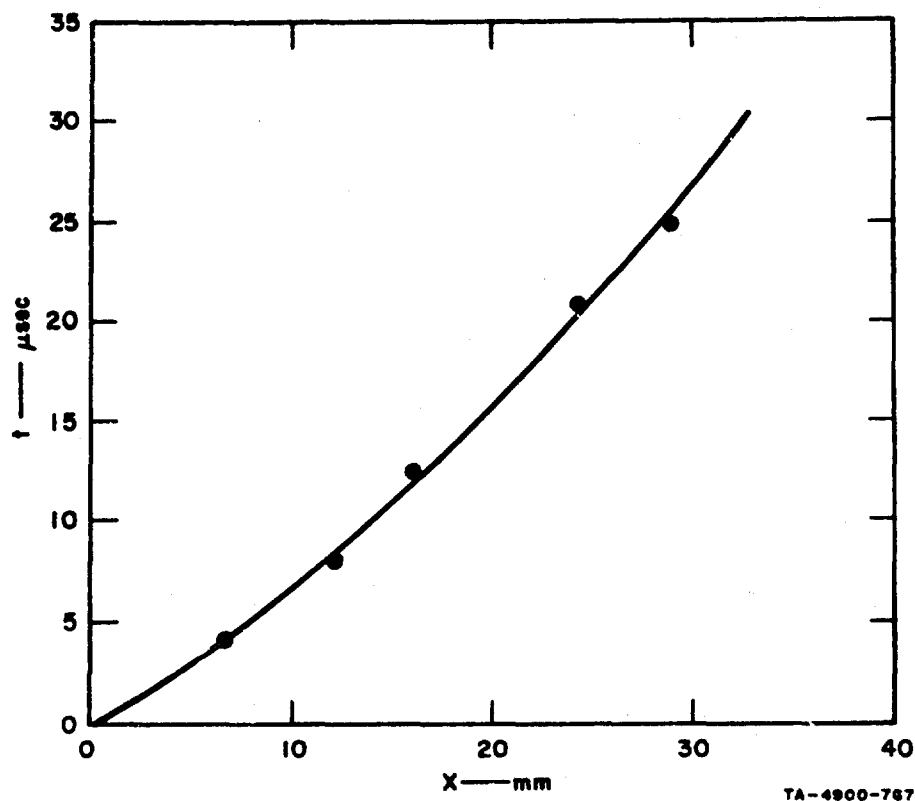


FIG. 10 POSITION OF THE CAVITATION FRONT AS A FUNCTION OF TIME

cavity pressure, the propagation of the "breaking front" (region of cavitation) will be supersonic, driven by the pressure jump $p_c - p_b$. Involved arguments are given to show that the breaking front can not advance at subsonic velocity (9).

A characteristic feature of all the framing pictures we have taken is the shape of the underwater cavitated region. It is interesting to note that the shape in the 45 μsec frame of Fig. 9 corresponds roughly to the surface of equal tension calculated by Kennard from Hilliard's data (8, Fig. 13, p. 12).

In the 25 μsec picture the products are being drawn up into the cavitated region by the rarefaction wave. This motion occurs predominately in the preceding 4 μsec . During this period of acceleration, instabilities of the products-liquid interface might develop depending upon the density of the detonation products at that stage.

Another feature in Fig. 9 is the line above the dome which is believed in this shot to be a reflection of the dome in the Plexiglas back panel of the water box. However, clear evidence of the air shock above the dome is seen in Fig. 11, which is a frame from a shot which was backlighted with an explosive-argon flash lamp placed behind the tank and slightly to the right. Here the shock is clearly delineated and refraction effects can be seen through it. A weak optical reflection of the air shock on the backboard can be seen at the right. Since the dome is driving the shock at about $1 \text{ mm}/\mu\text{sec}$, the pressure in the shocked air is about 0.01 kbar, and likewise this is the pressure within the dome when it is first formed.

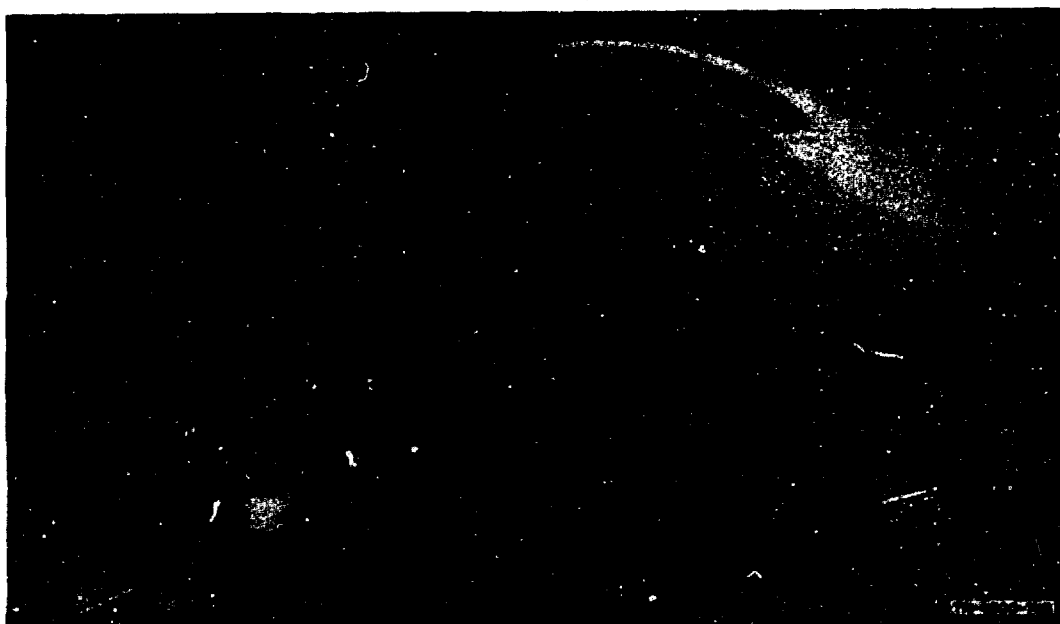


FIG. 11 BACKLIGHTED HIGH-SPEED FRAMING CAMERA PHOTOGRAPH SHOWING AIR SHOCK AHEAD OF CAVITATION DOME. An optical reflection of the air shock can be seen at the right. Time $58 \mu\text{sec}$. SRI Shot No. 11813.

B. Discussion

There are a number of points concerning the cavitated region that cannot be answered at the present stage of experimentation. Perhaps the most important is the question of whether there is a "Temperley spall" or not (3, pp. 53-66). There is no clear evidence of such a phenomenon in

our pictures, but it is not clear that there should be since such a layer, if it temporarily formed, would be expected to form droplets too small to be resolved by our camera. Such droplets might be indistinguishable from similarly fine bubbles.

It has been suggested by Kolsky (10, pp. 293-4) that layered cavitation is associated with the possibility of formation of a running crack. Spalling therefore occurs only with solids, or with liquids only when they are acting as solids because of an extremely high rate of stress loading. Kolsky estimates that for water the stress must build up in a time of the order of 10^{-11} sec to produce a brittle fracture. For sugar syrup with a viscosity of 400 poise, the characteristic time is of the order of 10^{-7} sec.

Closely associated with the question of spalling is the value of tensile strength to be assigned to liquids. Studies of dome formation indicate values for water from 0.03 to 0.3 kilobars (11, pp. 642-78). It is suggested that the tensile strength varies as $W^{1/3}/R$, where W is the weight of the explosive charge and R is the distance from the charge to the surface.

H. Kolsky (10) and T. H. Bull (12, 13) have measured tensile strengths in the laboratory with a pulse transmitted to water by a long steel bar from a small tetryl pellet. Bull's results suggest that the tensile strength of liquids is mainly controlled by the viscosity. The rate of stress used by Kolsky and Bull was quite low, and the tensile strength of water was found to be less than 0.02 kbar under those particular conditions. In our experiments, the shape of the pulse is not known (and may be complex from a P-40 plane-wave lens). There is evidence that the water supports tension for a short time, since the shock wave intersects the water surface beyond the edge of the dome.

These results indicating the importance of bulk cavitation are not in disagreement with other experimental work on explosive dissemination. The mottled appearance of radial radiographs taken at much later times may well have developed from small bubbles (3, p. 58). It is true, of course that these radiographs were taken after a number of reverberations

in divergent geometry. The appearance of the expanding cloud from a 3 in. bomblet as recorded by an image converter is not inconsistent with a finely cavitated foam (3, p. 7). Fastax pictures of expanded clouds appear to consist of many small jets consisting of dense foam (14, Fig. 7b). High-speed framing camera pictures of plastic bomblets also suggest that the material issuing from the case is a finely cavitated foam and further suggest that the jets are formed by the mode of case break-up (15). All this qualitative experimental information, which is not inconsistent with the foam hypothesis, accomplishes little toward a critical test of the proposal. Much experimental and theoretical work remains to be done before the proper position of cavitation can be assigned in the dissemination process. G. M. Muller has suggested that cavitation may affect agent degradation (3, p. 59) and this also needs further investigation.

No experiments have been performed on the effect of munition cases of various types on cavitation, although such experiments are not particularly difficult in this test geometry as long as the case is not too strong and thick. The first effects of a case are to maintain the pressure in the liquid and to slow the expansion. These effects will be more pronounced the higher the shock impedance of the case material. For a thin case, even when made of a high impedance material like steel, the effect of shock reflection will be noticeable for a short time only. After several reverberations in the steel, the motion of the liquid will be hardly distinguishable from that of the corresponding element in a fill (without case) whose thickness was increased so as to equal the mass of fill plus steel. Very thick, brittle cases of high shock impedance will, however, change the flow drastically; cavitation may be prevented until after case fracture, and occur only after jetting through the cracks is well established. It seems unlikely that the present test geometry could be used to observe these phenomena, although they may be very important in heavy walled munitions.

C. Conclusions

There seems to be no further doubt that fine bulk cavitation takes place in liquids under the action of explosives. Regardless of what is finally determined about the surface layer of liquid, the under-the-surface spread of the cavitation front leaves little doubt about what is happening there. However additional experimental and theoretical investigations are required for elucidation of the details of bulk cavitation.

The relation of pictures of bulk cavitation to dissemination devices is quite direct. In such a device the liquid will tend to cavitate in divergent flow at least as easily as in the cases we have photographed, since the pressure gradient behind the shock will be steeper in divergent flow. A thin metal case at the surface of the liquid will have little effect after several reverberation times and during those reverberations may induce cavitation directly behind the metal.

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13. ABSTRACT <p>The purpose of this study of boundary instability was to conduct a brief experimental investigation of the explosive-product/liquid interface and the liquid-air interface to ascertain if simple theoretical predictions are realized. The study was carried out with a Beckman Whitley Model 189 framing camera.</p> <p>Framing camera pictures of the explosive-products/liquid interface under the influence of motion imparted by an explosive show: (1) Some mixing occurs when the shock from the detonation enters the liquid. This early jetting apparently results from irregularities of the explosive surface, (2) If the jetting referred to above is pronounced it is not prevented by thin metal walls between the explosive and the liquid, and (3) For the geometry studied the product-liquid interface is quite stable in the period between entry of the shock into the liquid at the explosive-liquid boundary and its exit at the liquid-air boundary. (There is no acceleration during this period.)</p> <p>Framing pictures taken after the shock reaches the liquid-air interface show: (1) Rapid acceleration of the products takes place when the first rarefaction reaches the product-liquid interface. (This is a period when instabilities might develop.), and (2) the rarefaction wave reflected from the liquid-air surface causes fine random cavitation. There is no experimental evidence of layered cavitation.</p>			

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